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AN OBJECTIVE METHOD OF FORECASTING PRECIPITATION 24–48 HOURS IN ADVANCE AT SAN FRANCISCO, CALIFORNIA

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This is the first report of a study aimed at developing an objective method for forecasting the occurrence of rain at San Francisco, Calif., applicable to the period 24–48 hours after map time. Primarily, incentive for the study stems from the urgent need to furnish improved rain forecasts for the second day in advance to operational planning units of agriculture, industry, and transportation. The study is confined to the winter season and does not in any way touch upon summer or early autumn rain conditions.

In the six parts of this report an effort is made to present the various steps in the development of the study, in the order of their occurrence. This presentation is intended to demonstrate that useful results may be obtained with a minimum of effort from a relatively small sample of data, by utilizing synoptic experience as a basis from which to start, proceeding to express that experience in numerical parameters, and subjecting each parameter finally to statistical tests.

HISTORY

The outstanding studies dealing with rainfall forecasting on the Pacific Coast have all resorted to map typing in one form or another. In 1932, Reed [1], following to a large extent the system previously applied by Abercromby [2] to the Atlantic, developed the first system of weather types for the Northeast Pacific. All maps were placed in one of six classifications—Northerly, Northwesterly, Westerly, Southwesterly, Southerly, or Easterly—based on the direction of the predominating air currents in the area under consideration, i. e., the Northeast Pacific Ocean.

Reed's system should be considered the parent of all weather typing systems thus far developed for the Northeast Pacific. Although excellent, it has perhaps not received due recognition because (1) it is entirely descriptive; (2) it is not illustrated but in lieu of illustrations gives references to maps which are not available to many readers; and (3) it is general in scope and does not develop objective methods for making forecasts for any specific point or definitely defined area.

In July 1943, Brown [3] published an article on rainfall forecasting for the Los Angeles area, making certain modifications in the map types developed by Reed, and developing a somewhat objective system of arriving at the forecasts. Later in the same year the California Institute of Technology [4] published an elaborate system of map types based largely on pressure field configurations and the position and intensity of the North Pacific subtropical anticyclone. Finally, in 1946, Thompson [5], following the work of Reed and Brown to a considerable extent, developed a purely objective system of making rainfall forecasts for the period from 6 to 24 hours after map time for Los Angeles, Calif.

No resumé of map typing efforts would be complete without mention of the noteworthy use of type maps made for many years by the Fruit Frost Service of the Weather Bureau under the supervision and direction of Floyd D. Young. Unfortunately, none of the map typing work done by the Fruit Frost Service has been published.

Although in many ways the study treated in this report resembles Thompson's study, it differs in four important respects: (1) it is designed for forecasting rainfall for San Francisco instead of Los Angeles; (2) it deals with forecasts for a period 24 to 48 hours in advance rather than 6 to 24 hours in advance; (3) in order to extend the forecast period to cover the second day after map time, there is consideration of the predominant air currents over an area far upwind in the directions from which rain-producing perturbations usually approach San Francisco, whereas in Thompson's study the prevailing currents over a more limited area were considered; and (4) secondary parameters, i. e., those applying within given types, are quite different from those used by Thompson.

CLASSIFICATION OF MAPS INTO MAJOR TYPES

Aptly pointed out by Reed [1] is the fact that the Pacific area is admirably suited for classification of weather maps according to direction of air streams, because " . . . the relative uniformity of temperature and equality of level of the oceanic surface permit the isobars to reflect in significant degree the strength and direction of the major air streams in the lower atmosphere." Reed classified his maps by subjective evaluation of the air streams. The first problem in the present study was to develop a numerical or objective method of classification, as Thompson [5] did in the Los Angeles study, by a determination of the meridional and zonal components of air movement in certain areas, based on measurement of pressure gradients. The areas in which these measurements were made were selected on the basis of their special significance to forecasting the weather for San Francisco.

It is a matter of common knowledge in synoptic meteorology that, under the more or less constant influences of the oceans and continents and the systematically varying influences of the seasons, atmospheric currents tend to become set up in certain preferred flow patterns. It appeared logical, in the development of a system for measuring the component parts of typical flow patterns from which map types would be determined, to start

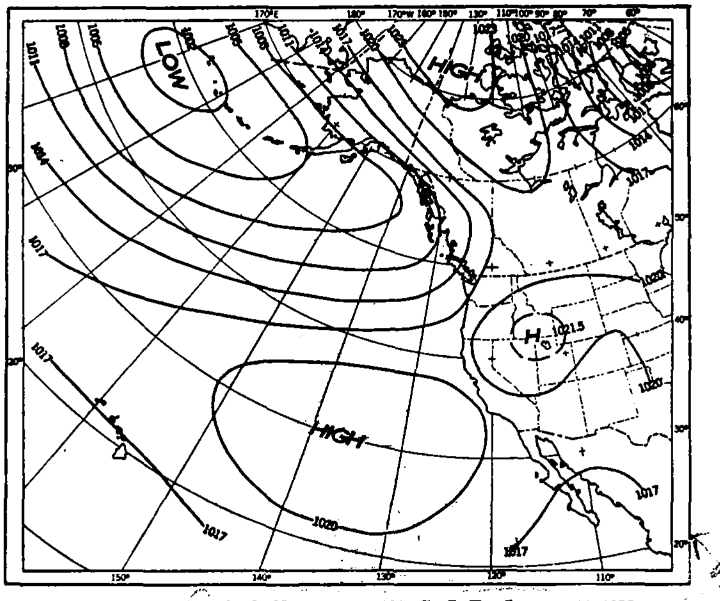

FIGURE 1(a).—Northerly Type map. 1200 G. C. T. January 11, 1935

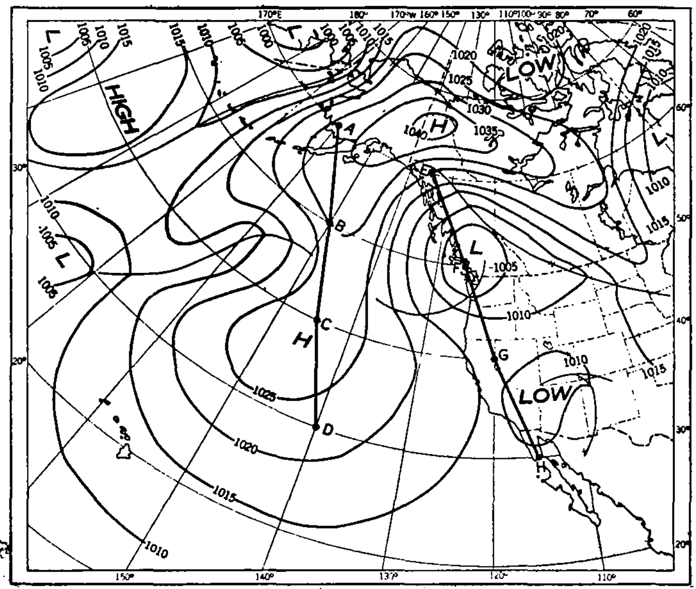

FIGURE 1(b).—Normal sea level pressure map for January

with measurements which would produce numerically large indications on those maps having the most unique flow patterns. Among the patterns, it is to be expected that the most unique would (a) depart most radically from normal patterns, or (b) accentuate the features of normal patterns.

By far the most unique of all the flow patterns observed in the Northeast Pacific is that described by Reed as the "Northerly Type," which coincides with Brown's "Type 2" and C. I. T. "Type A." An excellent example is shown in Figure 1(a). This type, which is characteristically rainy for San Francisco, represents an almost complete reversal of the normal pressure distribution, which can be seen by comparing Figure 1(a) with Figure 1(b). The former shows the Northerly Type map of January 11, 1935, 24 hours before the beginning of seven consecutive rainy days associated with the same map type, while the latter shows the normal sea level pressure distribution for January. While on the normal map pressure is relatively high along the continent and low at sea, the opposite is true of the Northerly Type map, on which the pressure is relatively low along the continent and high from 800 to 1,000 miles at sea.

In maps of the Northerly Type the predominant movement of rain-producing disturbances is from north to south, with a large positive (north-to-south) meridional flow along the coast and the adjacent ocean. In order to obtain a large positive meridional index on such a map, the difference in the pressures must be measured along two axes, one lying parallel to and near the axis of the controlling Pacific High cell and the other parallel to and touching upon the axis of the low pressure system dominating the coastal area.

It has been found that this result can be obtained [see Figure 1(a)] by subtracting the mean of pressures at points E, F, G, and H, which lie along a line approximating the mean position of the coastal troughs of Northerly Type maps, from the mean of pressures at points A, B, C, and D, which lie along a line approximating the normal axis of Highs associated with the same type. The value obtained is expressed symbolically as

$$\tfrac{1}{4}(A+B+C+D)-\tfrac{1}{4}(E+F+G+H)$$

and is referred to as M_a, or "Meridional A." In the map shown in Figure 1 (a) it amounts to 15 mb., which is large enough to satisfy the desire for a numerically large meridional index in typical Northerly Type maps.

The next step in testing the effectiveness of the tentatively selected meridional index points was to ascertan whether the same points would yield a numerically satisfactory negative meridional index on a Southerly Type map. The Southerly Type is the second most unique of Reed's classification, usually a fair-weather type for San Francisco, and represents an accentuation of certain features of the normal pressure distribution, with pressures higher than normal along the continent and lower than normal in the eastern Aleutians.

Figure 1(c) shows how the pressure values from the grid described in the preceding paragraph will produce a relatively large negative value for the meridional index when when applied to a typical Southerly Type map. The representative Southerly Type map of January 2, 1938, was followed after 24 hours by eleven consecutive days

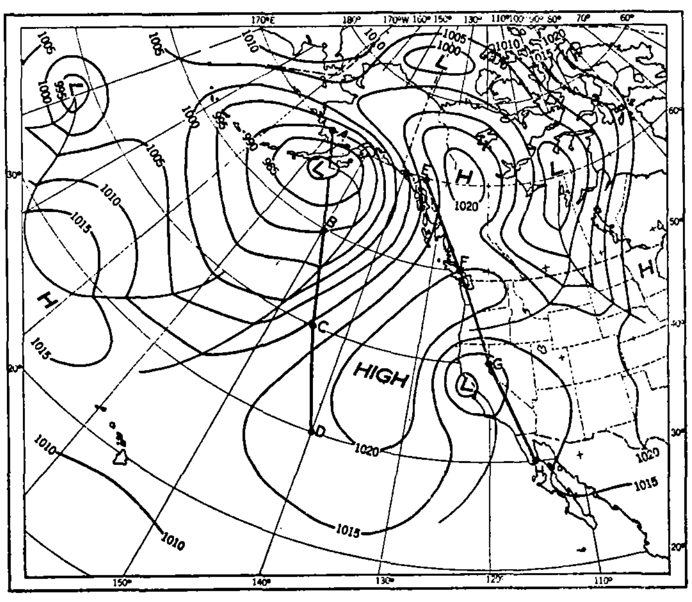

FIGURE 1(c).—Southerly Type map. 1200 G. C. T. January 2, 1938

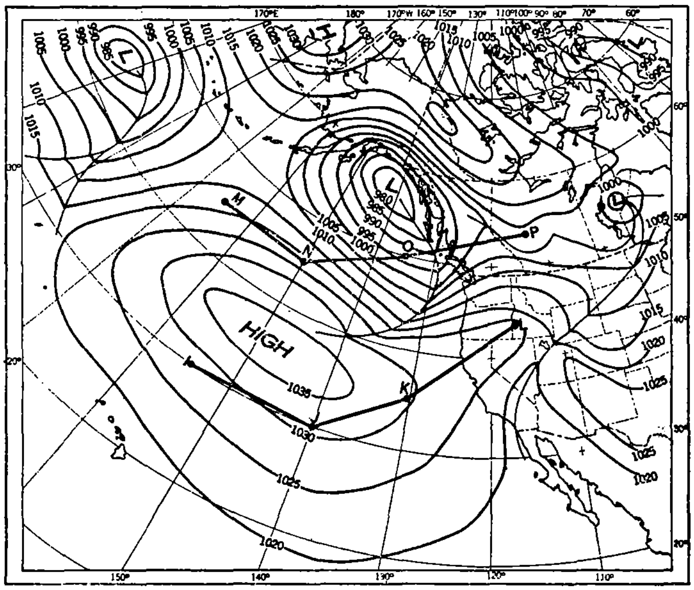

FIGURE 2(a).—Northwesterly Type map. 1200 G. C. T. January 1, 1933

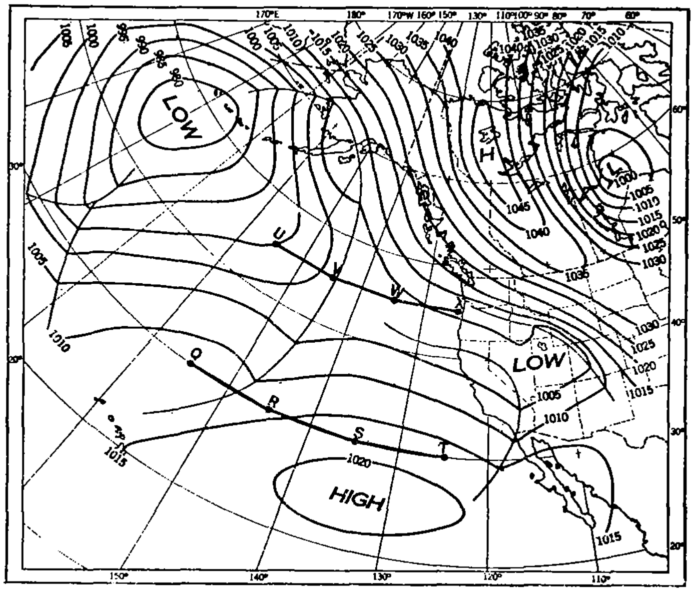

FIGURE 2(b).—Southwesterly Type map. 1200 G. C. T. February 16, 1936

of rainless weather at San Francisco. From it, the value of the meridional index, using the above formula, was computed as −8.0 mb., which indicated that the meridional axes selected would produce the desired large negative indices under Southerly Type conditions, as well as large positive indices under Northerly Type flow patterns.

Figures 2(a) and 2(b) illustrate the method for determining the zonal component of the local circulation. In Figure 2(a), points I, J, K, and L were selected, to be near the normal position of the axis of the Pacific high pressure cell as well as near the approximate average position of the center of the Plateau high pressure system when it exists. Points M, N, O, and P were selected to be roughly parallel to points I, J, K, and L, and to lie sufficiently far to the north of the latter to result in zonal indices numerically commensurate with the meridional indices obtained in the manner previously described. The zonal index was then obtained by subtracting the mean of the pressures at points M, N, O, and P from the mean of the pressures at I, J, K, and L. The value obtained is expressed symbolically as

$$\tfrac{1}{4}\,(\mathrm{I}+\mathrm{J}+\mathrm{K}+\mathrm{L})-\tfrac{1}{4}\,(\mathrm{M}+\mathrm{N}+\mathrm{O}+\mathrm{P})$$

and is referred to as Z_a, or "Zonal A."

After scaling off the local meridional and zonal indices, it is possible to classify a given map by plotting the indices on cartesian coordinates, illustrated in Figure 3. If the point plotted for a given map falls in the upper quadrant, a Northerly Type prevails; similarly, the other quadrants each indicate a specific type, as shown in Figure 3. However, it may be more convenient in actual practice to express the classification process symbolically as follows:

$$
\begin{array}{rl}
+M_a>|Z_a| & \text{Northerly Type} \\
-M_a>|Z_a| & \text{Southerly Type} \\
+Z_a>|M_a| & \text{Westerly Type} \\
-Z_a>|M_a| & \text{Easterly Type}
\end{array}
$$

This system of typing was tested on a sample of 237 maps taken from eight winter months—January and February of 1933, 1935, 1936, and 1938—which were selected as being representative of a wide variety of map types. Table 1 shows the number of maps falling in each type and the number of maps followed by "rain" and "no rain" days under each type. A "rain" day was defined as one in which a measurable amount of rain occurred at the official gauge in downtown San Francisco between 24 and 48 hours after the time of the map under consideration. Traces of rain were counted as "no rain," unless they occurred at the beginning or end of a period of measurable precipitation.

Figures in the table, showing 35 rain days against 8 no rain days, support the conception that the Northerly Type is characteristically rainy, and indicates a satisfactory segregation of rain days into this type. Figures on the Southerly Type, showing 43 no rain days against 18 rain days, agree with the original concept that this is predominantly a no rain type, but they do not show the preponderance of no rain days which experience would lead one to expect. In an attempt to improve this segregation of no rain days, a new zonal index (Z_b) was tested. This index consisted of a mean of pressures along latitude 50° N., subtracted from a mean along latitude 35° N. The sample of maps was reclassified using M_a and Z_b, with no significant gain in the segregation, and Z_b was abandoned.

TABLE 1

Map type	Number of maps	Rain days	No rain days
N	43	35	8
W	119	49	70
S	61	18	43
E	14	5	9
Total	237	107	130

In a further attempt to improve the Southerly classification, all maps of this type were inspected, and it was found that a significant number of the maps followed by rain days were of the type shown in Figure 2(b). The indices used originally, M_a and Z_a, place this type of map in the Southerly classification. It was rather obvious, however, that, as far as California is concerned, the predominant flow is westerly. In order to bring about a Westerly instead of a Southerly Type classification, there

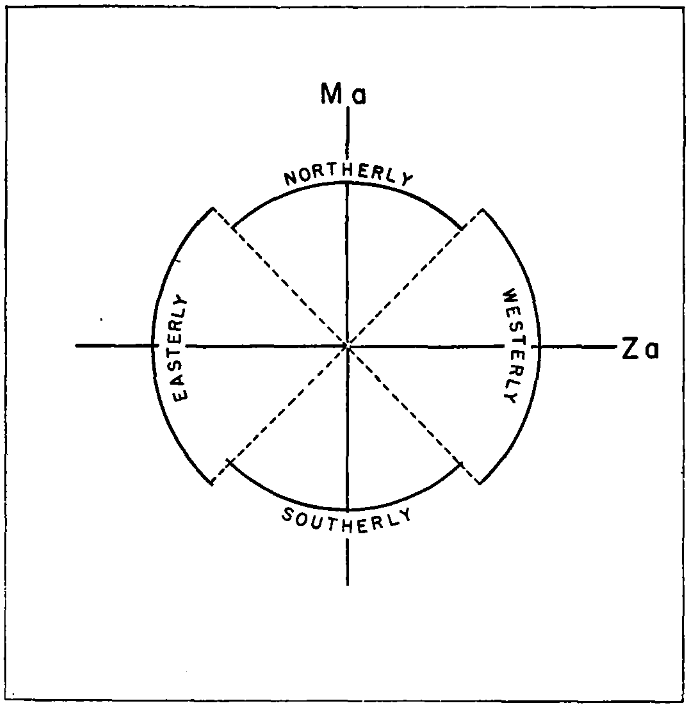

FIGURE 3.—Chart illustrating basis for plotting local meridional and zonal indices for a given map on cartesian coordinates to determine its type

must be a strongly positive zonal index. This can be obtained by computing the zonal index as the difference between the mean of pressures at points Q, R, S, and T along latitude 30° N., and U, V, W, and X along latitude 45°N. This index,

$$\tfrac{1}{4}\,(Q+R+S+T)-\tfrac{1}{4}\,(U+V+W+X),$$

is referred to a Z_c, or "Zonal C."

All of the 237 maps in the original sample were again reclassified, this time using M_a and Z_c. Results are shown in Table 2. Figures in this table show a segregation of no rain days for the Southerly Type as 62, against but 13 rain days, to be compared with 43 no rain days against 18 rain days resulting from the first attempt at classification, shown in Table 1. However, some skill was lost in this attempt at segregation relative to the Northerly Type maps. They show only 31 rain days against 14 no rain days, as compared with the first test ratio of 35 to 8.

TABLE 2

Map type	Number of maps	Rain days	No rain days
N.	45	31	14
W.	103	59	44
S.	75	13	62
E.	14	4	10
Total	237	107	130

Comparison of Tables 1 and 2 immediately suggested that the next step should be to combine the best features of each classification and obtain a high degree of segregation of no rain days under the Southerly Type without loss of the excellent segregation of rain days under the Northerly Type. This was accomplished by the simple expedient of first measuring the meridional index, M_a. If positive, it was used in conjunction with Z_a, and if negative, with Z_c. The table given below expresses this symbolically.

$+M_a>\lvert Z_a\rvert$	Northerly Type	
$+M_a<+Z_a$	Northwesterly Type	Westerly Type
$-M_a<+Z_c$	Southwesterly Type	
$-M_a>\lvert Z_c\rvert$	Southerly Type	
$-M_a<-Z_c$	Southeasterly Type	Easterly Type
$+M_a<-Z_a$	Northeasterly Type	

Once again all of the 237 original maps were reclassified, this time according to the foregoing system, with the results shown in Table 3.

TABLE 3

Map type	Number of maps	Rain days	No rain days
N.	43	35	8
W.	101	52	49
S.	75	13	62
E.	18	7	11
Total	237	107	130

These figures show that the best features of each test had been preserved: the ratio of 35 rain to 8 no rain days was retained for the Northerly Type maps, and 63 no rain to 13 rain days for the Southerly Type. This led to a decision to use the latter criteria for classification of January and February maps.

TREATMENT OF INDIVIDUAL TYPES

Northerly Type.—The next problem in the study was to effect a satisfactory segregation of rain and no rain days within each individual type. Beginning with the Northerly Type, an attempt was made to show a relationship between the location and strength of the Pacific high pressure cell and the occurrence of rain. One of the preconceived hypotheses was that rain occurring with a Northerly Type map was dependent to some extent on the position of this cell. No relationship could be demonstrated, however, and it was concluded that while location and strength of the high pressure cell are important factors in determining the map type, they are of no further help in separating the rain days from no rain days within the type.

Study of the entire group of Northerly Type maps in the sample revealed that when the large area of low pressure associated with this type shifts rather far eastward or southward, rain at San Francisco terminates. However, it was rather difficult to define the center of this large Low, due to the fact that once it is centered east of the coast, it becomes broken up into several more or less related centers. It was finally found that fairly good separation of rain from no rain days within the Northerly Type could be obtained by plotting the point of lowest pressure in the area bounded approximately by 37° N. and 60° N. lat. (or the Aleutian Islands chain), and 110° W. and 170° W. long. A plot of these positions for the original sample of 43 Northerly Type maps is shown in Figure 4. Dots indicate rain days; and circles, no rain days. The actual area considered in selecting the point of lowest pressure is outlined. The smoothed curve was drawn to separate as far as possible the rain and no rain points. Final location of this curve was determined by deciding upon what position would give the highest skill score in the forecast verification that follows.

By forecasting rain for each case when the point fell to the left of the line of separation, and no rain when it fell to the right, the following verification scores were obtained, using all the days included in the sample of Northerly Type maps, i. e., the data plotted in Figure 4.

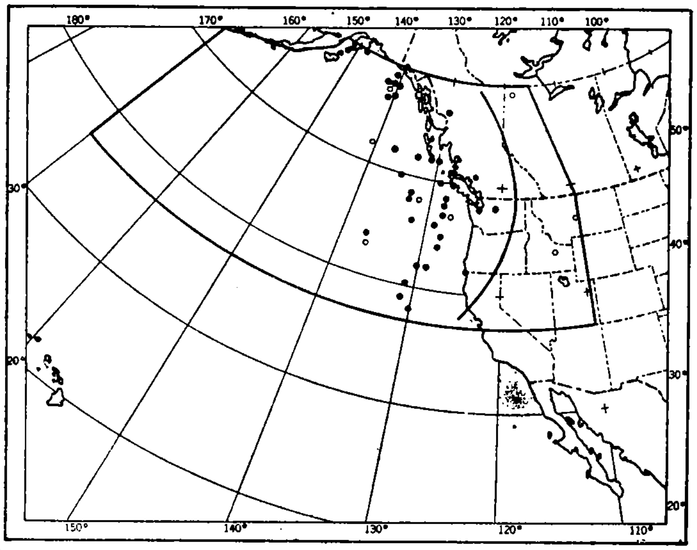

FIGURE 4.—Plotted positions of points of lowest pressure in area from 37° to 60° N. lat., 110° to 170° W. long., for each Northerly Type map in sample data. (Dots indicate rain; circles, no rain, occurring between 24-48 hours after map time.)

TABLE 4

		FORECAST Rain	No rain	Total
OBSERVED	Rain	35	0	35
	No rain	5	3	8
	Total	40	3	43

Percent correct=88
Skill score [1]=.80

Considering the fact that the forecast is for the second day in advance, i. e., 24 to 48 hours from map time, both the percent correct, 88, and the skill score of .80 may be regarded as excellent. While the study of additional cases and the use of additional parameters might yield a higher skill score, the magnitude of possible improvement was limited enough to justify dropping investigation of this map type temporarily to proceed with the study of other types.

Northwesterly Type.—In the finally adopted system of classification, M_a was used with Z_a if the meridional index was positive, and with Z_c if it was negative. This resulted in some of the Westerly Type maps being based on Z_a, some on Z_c. To separate these, the Westerly Types utilizing Z_a are referred to as Northwesterly, since they involve a positive (north-to-south) meridional component of flow; those utilizing Z_c are referred to as Southwesterly, because they involve a negative (south-to-north) meridional component.

[1] The skill score, S_c, in this study is defined by

$$S_c=\frac{C-E_c}{T-E_c},$$

where C=number of correct forecasts,
E_c=number of forecasts expected to be correct due to chance, and
T=total number of forecasts.
It has a value of unity when all forecasts are correct, and zero when the number of correct forecasts is equal to the number expected to be correct due to chance. In this study, the number of forecasts expected to be correct by chance is defined as the number expected correct from an equal number of random forecasts of rain days and no rain days, with the proportion of rain days to no rain days in accordance with climatological averages for the forecast period. Hence, the number of forecasts expected to be correct on this basis may be determined by

$$E_c=R\times f_r+N\ (1-f_r),$$

where R=observed number of rain days,
N=observed number of no rain days, and
f_r=relative frequency of occurrence of rain days during the period covered by forecasts, determined from climatological data (Example: if during a given period of 70 days it rains on the average of 23 days, f_r would be $^{23}/_{70}$).

In attempting to separate rain from no rain cases in the Northwesterly Type, it was found that, contrary to findings concerning the Northerly Type, the location of the Pacific high pressure cell was of great importance. If the cell was centered north of latitude 30° N. and east of 145° W. long., rain was highly improbable; but if it shifted to the south or west of these limits, the probability of rain was greatly increased. This relationship is shown in Figure 5. In order to be as objective as possible in dealing with the location of the High, the center of the high pressure cell was defined as the point of highest pressure to be found between the west coast and 160° W. long., and between 20° N. and 50° N. lat. This point was plotted, in Figure 5, for each Northwesterly Type map in the sample. Here, again, rain days are indicated by dots and no rain days by circles. The tendency for rain to be associated with a westward shift of the high pressure cell is clearly indicated. In actual practice the cell seems sometimes to undergo a progressive movement to the west. At other times it appears to break down east of 145° W. long., while a new cell moves into the area between 145° W. and 160° W. long. In Figure 5 the line of separation giving the highest possible skill score was drawn between rain and no rain points. Forecasts made from these data, based on this line of separation, would have given the following verification scores.

TABLE 5

		FORECAST Rain	No rain	Total
OBSERVED	Rain	15	2	17
	No rain	3	19	22
	Total	18	21	39

Percent correct=87
Skill score=.74

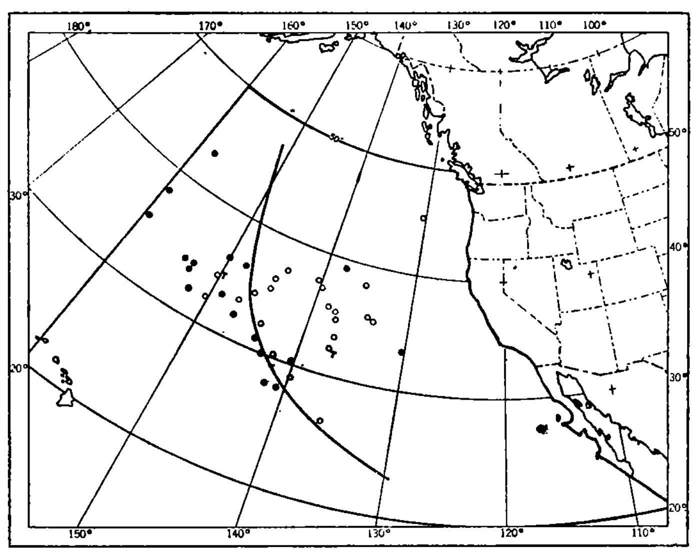

FIGURE 5.—Plotted positions of points of highest pressure from coast to 160° W. long., 20° to 50° N. lat., for each Northwesterly Type map in sample data. (Dots indicate rain; circles, no rain, occurring between 24-48 hours after map time.)

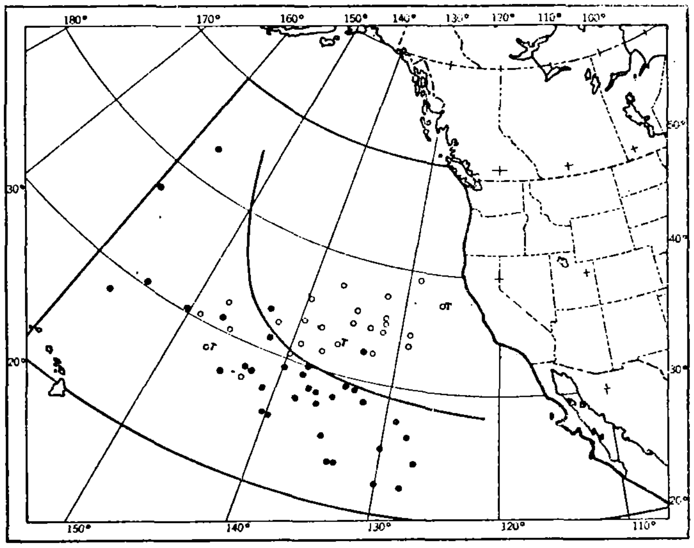

FIGURE 6.—Plotted positions of points of highest pressure from coast to 160° W. long., 20° to 50° N. lat., for each Southwesterly Type map in sample data. (Dots indicate rain; circles, no rain, occurring between 24–48 hours after map time.)

Southwesterly Type.—This type, defined as one in which $-M_a<+Z_c$, was treated in much the same manner as the Northwesterly. It is known that, as suggested by the type name, the Pacific high pressure cell usually shifts to the south or the southwest prior to the onset of rain, although there are a few cases in which it simply weakens while a stronger high pressure cell appears farther west or northwest, as in the Northwesterly Type. Figure 6 represents the plot of positions of the center of the high pressure cell for all cases of Southwesterly Type maps found in the original sample maps. Here again the center of the High was defined as the point of highest pressure between the West Coast and 160° W. long., and between 20° and 50° N. lat. The line of separation which was drawn between rain and no rain days yielded the following verification scores for forecasts made from these sample data.

TABLE 6

		FORECAST		
		Rain	No rain	Total
OBSERVED	Rain	33	2	35
	No rain	6	21	27
	Total	39	23	62

Percent correct=87
Skill score=.75

Southerly Type.—The position of the Pacific high pressure cell loses its significance when applied to Southerly Type maps, necessitating the use of other criteria for this type. The predominant movement of individual storms of this type is toward the north. Successive storms develop in a broad trough of low pressure and move rapidly to the north. In a majority of these situations the broad trough advances slowly eastward, maintaining enough of its original intensity to produce rain eventually at San Francisco. In a few instances the trough weakens to a degree which does not permit rain to accompany its passage over the coast. It was found that both the intensity and the proximity of the trough, as related to its potentialities as a rain producer for the second day in advance, can be judged rather successfully from pressures at 35° N. lat., 130° W. long., and 35° N. lat., 140° W. long. Figure 7 shows a plot of these points for all of the Southerly Type maps in the original sample. Pressures at 35° N., 130° W., were plotted as abscissa, while those at 35° N., 140° W., were plotted as ordinates. Dots indicate rain days; circles, no rain days. The line of separation which was drawn between rain and no rain days in this case gave the following verification scores for forecasts made from these sample data.

TABLE 7

		FORECAST		
		Rain	No rain	Total
OBSERVED	Rain	8	5	13
	No rain	2	60	62
	Total	10	65	75

Percent correct=91
Skill score=.77

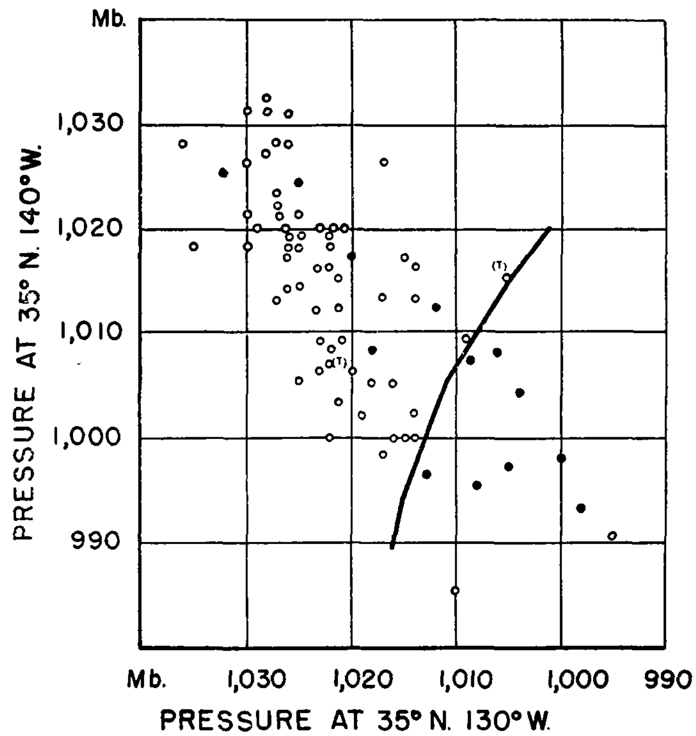

FIGURE 7.—Plotted pressures for designated latitude and longitude for each Southerly Type map in sample data. (Dots indicate rain; circles, no rain, occurring between 24–48 hours after map time.)

Verification scores for all types exclusive of Easterly.—Since there were but 18 cases of Easterly Type maps in the original sample, these were not treated at this stage of the study but were laid aside for later consideration. Combining verification scores for all cases in the original sample, exclusive of the Easterly Type, gives the following score.

TABLE 8

		Forecast: Rain	Forecast: No rain	Total
Observed	Rain	91	9	100
	No rain	16	103	119
	Total	107	112	219

Percent correct=89
Skill score=.77

TEST OF SYSTEM ON INDEPENDENT DATA

By the usual standards the scores obtained from the original data may be regarded as excellent for forecasts of rain or no rain 2 days ahead. The question immediately arose, however, as to whether the system would produce comparable results when applied to independent data. It was decided to test the system by applying it to independent data taken from 4 months of December and 4 of March. The months used were December of 1931, 1932, 1933, and 1934, and March of 1932, 1933, 1934, and 1935.

Verification of the December forecasts made by use of this system is given in Table 9, while Table 10 shows similar data for the March forecasts. These two tables, along with January and February verifications of original data, are summarized and compared in Table 11. They indicate definitely that the system holds nearly as well for both December and March as it did for January and February.

The over-all skill on all map types for the various months is compared in Table 12. Perhaps it should be pointed out that lower skill scores should be expected in March since the normal predominance of no-rain weather in that month is greater than in December, January, or February.

TABLE 9.—*Verification of test data for months of December 1931, 1932, 1933, and 1934*

			Forecast: Rain	Forecast: No rain	Total	
N Type	Observed	Rain	12	0	12	Percent correct=82
		No rain	3	2	5	Skill score=.70
		Total	15	2	17	

			Forecast: Rain	Forecast: No rain	Total	
NW Type	Observed	Rain	11	1	12	Percent correct=89
		No rain	2	14	16	Skill score=.77
		Total	13	15	28	

			Forecast: Rain	Forecast: No rain	Total	
SW Type	Observed	Rain	21	1	22	Percent correct=88
		No rain	4	16	20	Skill score=.76
		Total	25	17	42	

TABLE 9.—*Verification of test data for months of Decmber 1931, 1932, 1933, and 1934*—Continued

			Forecast: Rain	Forecast: No rain	Total	
S Type	Observed	Rain	0	7	7	Percent correct=77
		No rain	0	24	24	Skill score=.42
		Total	0	31	31	

			Forecast: Rain	Forecast: No rain	Total	
Combined (N, NW, SW, S Types)	Observed	Rain	44	9	53	Percent correct=85
		No rain	9	56	65	Skill score=.68
		Total	53	65	118	

TABLE 10.—*Verification of test data for months of March 1932, 1933 1934, and 1935*

			Forecast: Rain	Forecast: No rain	Total	
N Type	Observed	Rain	13	0	13	Percent correct=78
		No rain	4	1	5	Skill score=.64
		Total	17	1	18	

			Forecast: Rain	Forecast: No rain	Total	
NW Type	Observed	Rain	3	0	3	Percent correct=81
		No rain	4	14	18	Skill score=.43
		Total	7	14	21	

			Forecast: Rain	Forecast: No rain	Total	
SW Type	Observed	Rain	11	1	12	Percent correct=77
		No rain	9	24	33	Skill score .41
		Total	20	25	45	

			Forecast: Rain	Forecast: No rain	Total	
S Type	Observed	Rain	3	0	3	Percent correct=100
		No rain	0	30	30	Skill score=1.00
		Total	3	30	33	

			Forecast: Rain	Forecast: No rain	Total	
Combined (N, NW, SW, S Types)	Observed	Rain	30	1	31	
		No rain	17	69	86	Percent correct=85
		Total	47	70	117	Skill score=.60

TABLE 11.—*Summary of verification scores on original sample data (Jan., Feb.) and test data (Dec., Mar.)*

Months	N Type		NW Type		SW Type		S Type		N, NW, SW, S Types	
	Skill score	Per-cent cor-rect	Skill score	Per-cent cor-rect	Skill score	Per-cent cor-rect	Skill score	Per-cent cor-rect	Skill score	Per-cent cor-rect
Jan.-Feb.	.80	88	.74	87	.75	87	.77	91	.77	89
Dec.	.70	82	.77	89	.76	88	.42	77	.68	85
Mar.	.64	78	.43	81	.41	77	1.00	100	.60	85

TABLE 12

	Jan. and Feb.	Dec.	Mar.
Skill score	.77	.68	.60
Percentage correct	89	85	85

Examination of Table 11 shows that the skill in forecasts from Southerly Type maps was appreciably lower in December (.42) than in January and February (.77). By reference to Table 9 it can be seen that this resulted from seven cases in which no rain was forecast and rain was observed. Upon examination of the maps on which these failures occurred, it was noted that most of them behaved as Northerly rather than Southerly Types. Their classification as Southerly was brought about by the fact that the pressure points used in determining the meridional index were too far west to obtain a representative index for December. This appears to be closely related to the frequent prevalence of blocking mechanisms in December, with relatively less significance attributable during that month to pressures west of the Pacific Coast. Consideration suggests that during the early part of the rainy season, i. e., November and December, the meridional index might be determined from pressures at points located about 5 degrees east of those found most satisfactory for January and February. This supposition will be tested in future studies.

In contrast with December, the verification of March data indicates the highest possible skill score on Southerly Type maps. Blocking mechanisms are relatively less frequent on the Pacific Coast in March than in December. Hence, the pressure points set up for determining the meridional index in January and February work with greater success in March than in December.

The tests indicated that skill in dealing with Northwesterly and Southwesterly Types will be lower in March than in January and February. In Table 11 it is seen that for the Northwesterly Type the skill score for March was but .43 as compared to .74 for January and February. For the Southwesterly Type the scores were .41 for March and .75 for January and February. Reference to Table 10 shows that the loss of skill in Northwesterly and Southwesterly Types for March was brought about by forecasting rain which did not occur. It will be recalled that the forecast for these types is based on the position of the Pacific High. No account is taken of location of Lows or of the pressure values at or near San Francisco. It appears that in March the mere shifting southward or westward of the high pressure center is not as significant as it is in midwinter. Some other variable, such for example as the pressure value at some critical point upwind

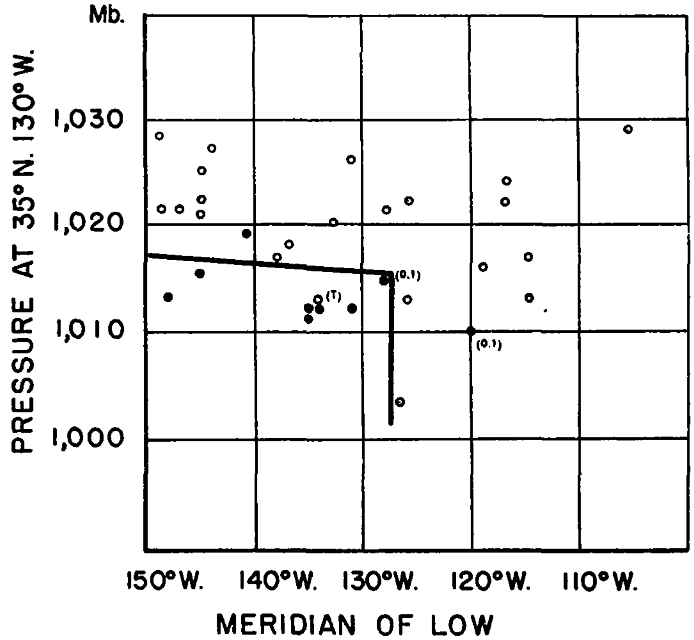

FIGURE 8.—Pressure at 35° N. lat., 130° W. long., plotted against the meridian of the most westerly low center lying between 105° to 150° W. long., for all Easterly Type maps, December through March

from San Francisco, may have to be used in conjunction with the location of the high pressure center if scores for forecasts on these types comparable to the January and February forecast scores are to be obtained. The high pressure cells in March are often so strong and extensive that the pressure upwind from San Francisco may not drop to values normally associated with rain even when the center of the cell drops far to the south or west of its normal position. It is also possible that verification of these types for March might be improved by drawing up special graphs similar to Figures 5 and 6 but based solely on March data.

Notwithstanding the difficulties encountered in dealing with Southerly Type maps in December and with Northwesterly and Southwesterly Types in March, it may be stated with confidence that the objective method can be applied with a considerable degree of success in all months from December to March, inclusive.

THE EASTERLY TYPE

After the test maps for December and March were typed, enough cases of the Easterly Type were at hand to permit statistical treatment. It will be recalled that the Easterly Type was defined as one in which $-M_a < -Z_c$, or $+M_a < -Z_a$. In considering this type the thought immediately occurs that, although the predominant flow over the area considered is from east to west, there must be a significant west or southwest flow in those instances in which rain ensues at San Francisco. Also occurring is the thought that with easterly flow predominating, the eastward advance of any rain-producing disturbance from the ocean should be relatively slow. Hence, the pressure at some point not too far southwest of San Francisco should give a good indication of the proximity of rain.

To test this theory the pressures at 35° N. lat., 130° W. long., and 35° N. lat., 140° W. long., were plotted in the same manner as in the case of the Southerly Type. The scatter diagram showed a rather good segregation of rain and no rain days but did not permit the drawing of a smooth line of separation. It was then decided to plot the geographical coordinates of the most westerly low pressure center located between 20° and 50° N., and 105° and 150° W. This, too, produced good segregation, but the best line of separation appeared to be an ellipse.

Although neither of these diagrams was deemed satisfactory for use as a forecasting tool, they served the purpose of pointing the way to an acceptable one. It was noted that on one, the pressure at 35° N., 130° W., was the predominant factor in producing segregation of rain from no rain points, while on the other, the meridian of the low pressure center was the most important factor. The obvious follow-up to this was to plot these two parameters against one another. Figure 8, on which rain days are dots and no rain days are circles, shows a plot of these values for all Easterly Type maps studied. The best line of separation between rain and no rain days gives the following verification scores for forecasts made from these sample data.

TABLE 13

		FORECAST		
		Rain	No rain	Total
OBSERVED	Rain	7	2	9
	No rain	1	21	22
	Total	8	23	31

Percent correct=90
Skill score=.77

This table includes data from all four months, December, January, February, and March, and no formal test has been run on independent data. The system worked satisfactorily on several Easterly Type maps from April and May of 1947.

CONCLUSIONS

The conclusions to be drawn from this study, some of which have already been mentioned, are summarized as follows:

1. The method developed is highly objective in that two forecasters applying it to the same map will arrive at the same forecast.
2. If used during January and February for the purpose of forecasting rain or no rain during the period 24 to 48 hours after map time, the method will give forecast scores equal to or better than the scores made on official forecasts in the past for the same period.
3. If used during December and March, the method will give slightly less accurate results than in January and February, but the December and March scores will be satisfactory, especially when compared with official forecast scores of the past.
4. The method is weakest on Southerly Type maps in December and on Northwesterly and Southwesterly Type maps in March.
5. While the method is based on the study of 1200 G. C. T. maps, day-to-day tests on maps for other periods of the day indicate that with but few exceptions it is equally applicable to them.
6. Day-to-day application of the method indicates that times of the beginning of precipitation can be fairly well anticipated by comparing forecasts made by this method from successive 6-hourly maps.
7. Scrutiny of the individual maps involved in this study leads to the belief that even better results can be obtained by dividing some of the major types into subtypes and then using additional parameters for segregating "rain days" and "no rain days" therein.
8. Cursory tests on other stations within a 150-mile radius of San Francisco indicate that the same system will show considerable skill when used without modification. However, for the best results, separate scatter diagrams for each type should be constructed for each station.
9. While precipitation has not been treated quantitatively in this study, it was observed in working with the data that there was a relationship between the amount of rain recorded and the point on the scatter diagram representing the map 24 to 48 hours before the rain. This leads to the belief that, with some modifications and additions, this method will offer a promising approach to quantitative precipitation forecasting.

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